Example Section of the SRD: High-redshift studies of AGN

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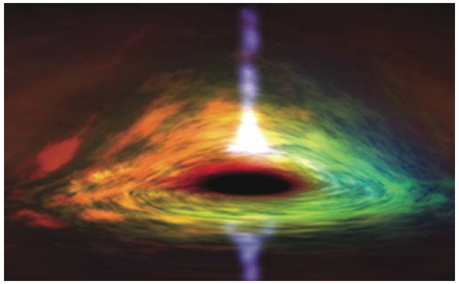
NASA GSFC

Organization of the Science Requirements Document

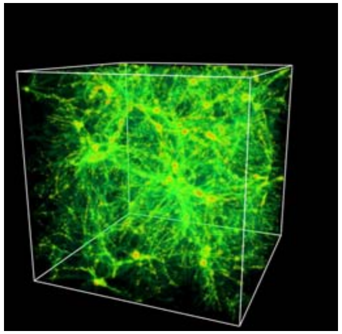
3-4 chapters organized around the science goals of the mission:



Black Holes

Observe hot matter spiraling into **Black Holes** to test the effects of General Relativity

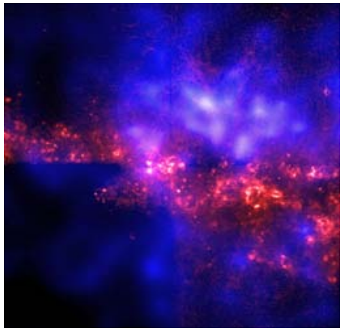
Trace their **evolution with cosmic time**, their contribution to the energy output of the Universe and their effect on galaxy formation



Dark Matter and Dark Energy

Use clusters of galaxies to trace the locations of **Dark Matter** and as independent probes to constrain the amount and evolution of **Dark Energy**

Search for the **missing baryonic matter** in the Cosmic Web



Cycles of Matter and Energy

Study dynamics of **Cosmic Feedback**

Creation of the elements in **supernovae**, The equation of state of **neutron stars, Stellar activity, proto-planetary systems** and X-rays from **solar system objects**

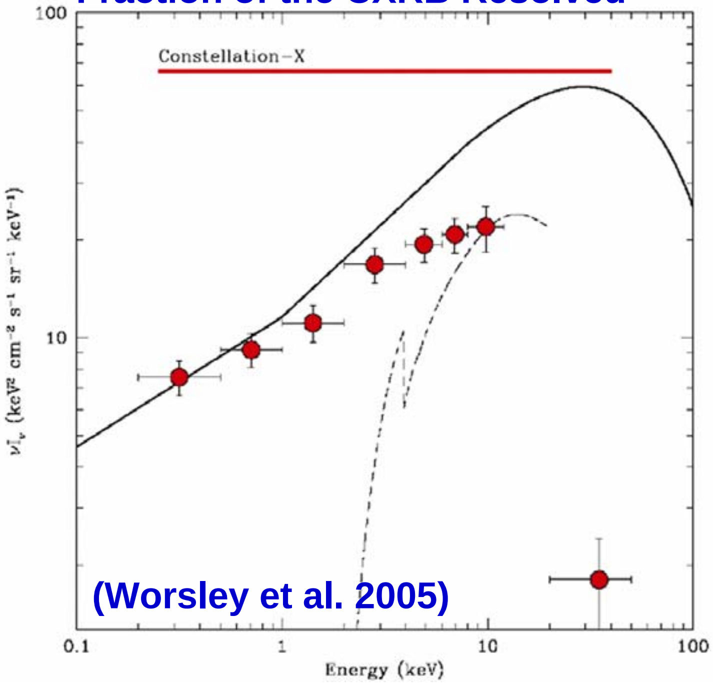
Organization of the Science Requirements Document

- Under each chapter are several specific science investigations (measurements) to be carried out by Constellation-X
- Each of these science investigations has these six parameters:
  - Bandpass
  - Sensitivity/Effective Area
  - Spectral resolution
  - Angular Resolution
  - Instantaneous Field of View
  - Other Requirements (specific to this particular investigation)
- Numbers should be quoted at specific (multiple) energies
- We arrive at these numbers by what the science requires but there are some science topics beyond the scope of the Constellation-X mission.

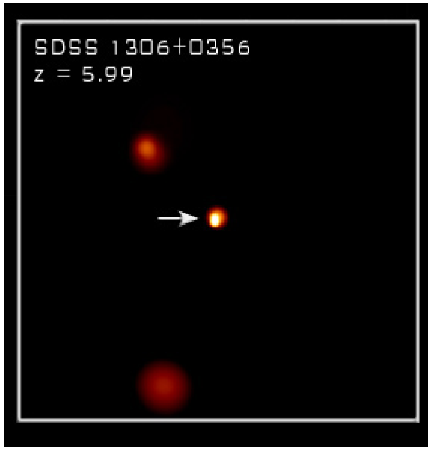
SRD Example: High-redshift studies of AGN

- Two science investigations currently in the SRD on high-z AGN:
  - ***AGN making the Cosmic X-ray Background (mostly z~1 Seyfert galaxies)***
    - This has been one of the science drivers for the Constellation-X mission
    - Redshift surveys show that the bulk of these AGN are obscured AGN at z~0.8 (e.g., Barger et al. 2004)
    - Only 3% of the E>10 keV CXRB has been resolved, so detecting hard components from faint AGN will also be critical
  - ***z>4 luminous AGN (QSOs)*** (Bechtold talk)
    - Chandra/XMM have been successful at detecting such AGN through follow-up of optically selected sources (e.g., SDSS QSOs)
    - These studies extend up to z~6.5

Fraction of the CXRB Resolved



(Worsley et al. 2005)

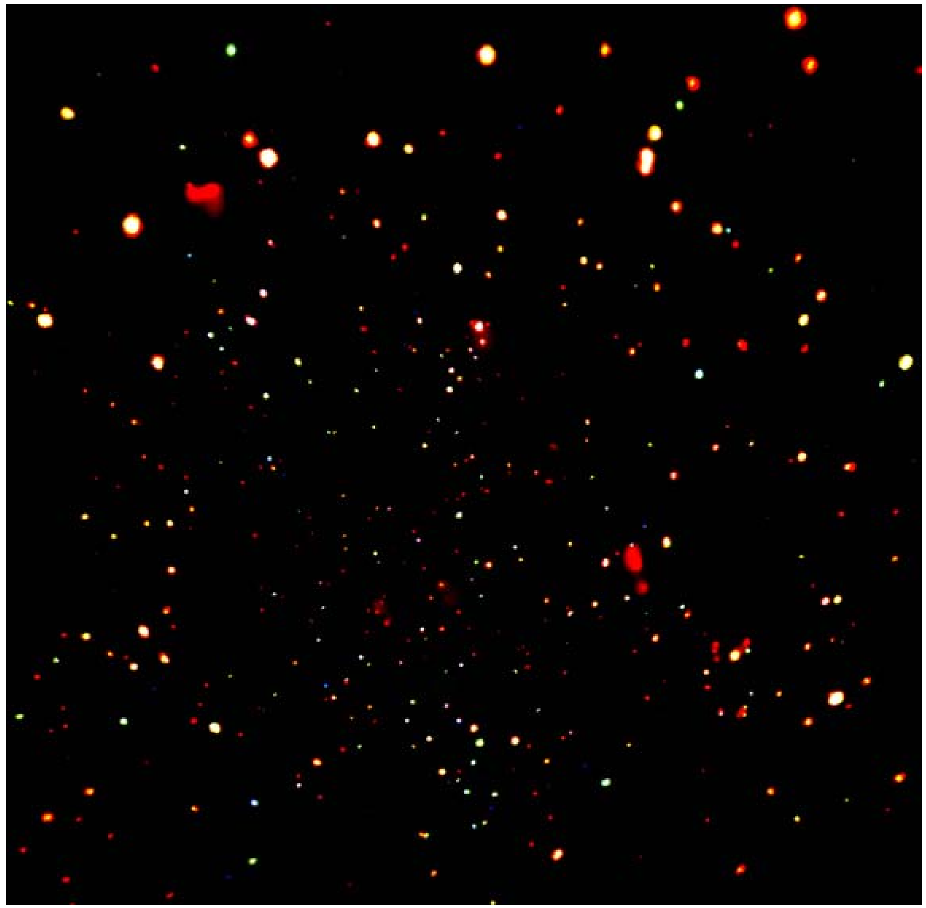


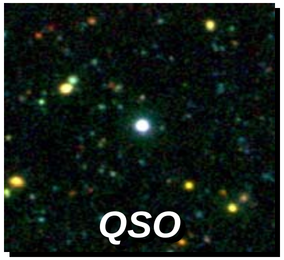
Brandt et al. (2004)

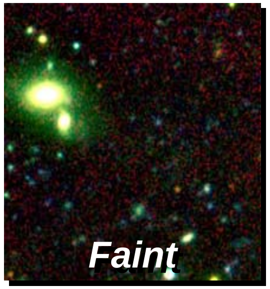
The CXRB & The Chandra Deep Fields

Chandra has resolved the X-ray background into active galactic nuclei (AGN) with a space density of a few thousand per sq deg

- Con-X will gather high-resolution X-ray spectra of the elusive optically faint X-ray sources
- Target sensitivity is level at which 80% of the 0.5-2 keV CXRB is resolved
  (~2 x 10^{-15} erg cm^{-2} s^{-1}, 0.5-2 keV)







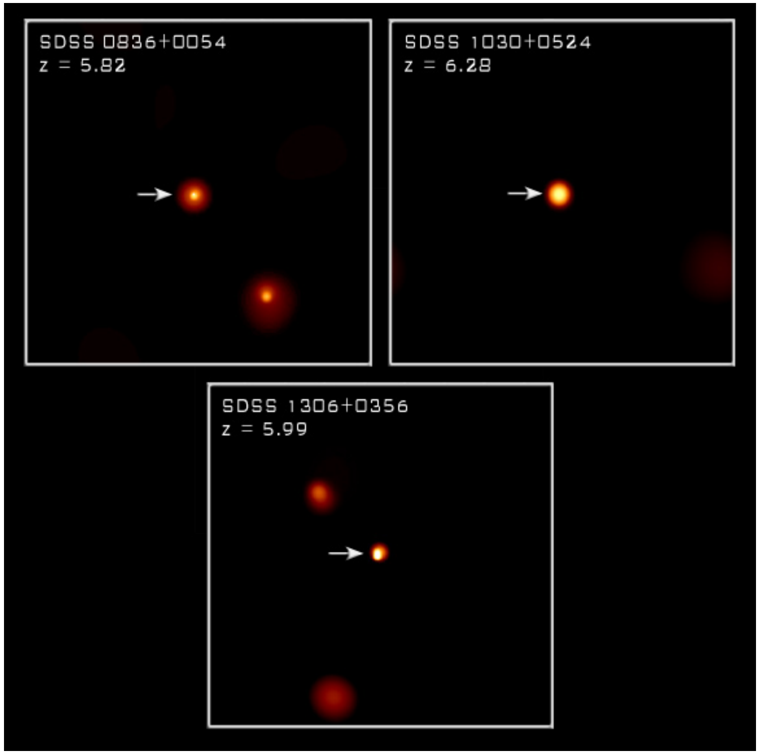
2 Megasecond Observation of the CDF-N
(Alexander et al. 2003)

Chandra sources identified with mix of active galaxies and normal galaxies, many are optically faint and unidentified

X-ray Detections of High Redshift QSOs

- Chandra has detected X-ray emission from multiple high redshift quasars at z ~ 6 found in the Sloan Digital Sky Survey (3 examples shown)

- Flux of 2-10 x 10^{-15} erg cm^{-2} s^{-1} beyond grasp of XMM-Newton, Chandra or Suzaku high resolution spectrometers, but within the capabilities of Constellation-X to obtain high quality spectra

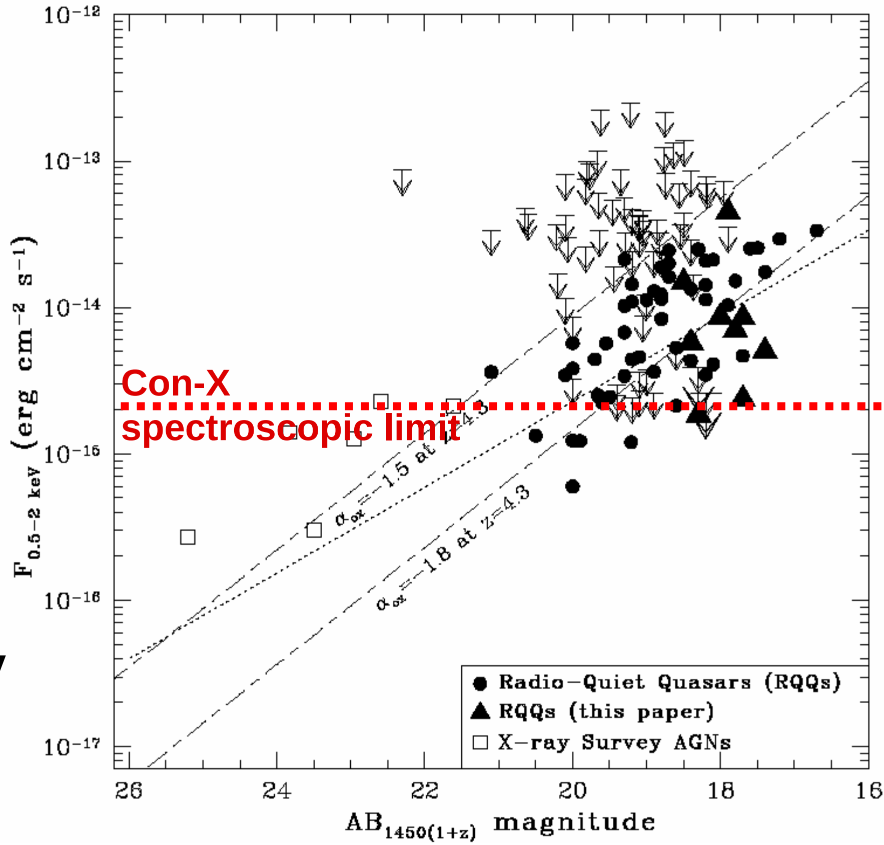


High resolution spectroscopy enables study of the evolution of black holes with redshift and probe the intergalactic medium of the early universe

High Redshift AGN (Opening Paragraphs in SRD)

- **Each SRD investigation begins with 1-2 paragraphs giving background & details of the measurement**
- **# of X-ray detections at *z* > 4 has increased from 6 in 2000 to ≈ 100 today.**
- **Poor photon statistics currently**
- **Science topics**
  - **Are there any differences in accretion disk environment of luminous AGN over observed 12 billion year interval?**
  - **Is there an “X-ray Baldwin Effect” where e.g., covering fraction decreases with luminosity, explaining the lack of Fe Kα lines in these high-z AGN (e.g., Page et al. 2004)**
- ***Con-X* has the sensitivity to identify and study Fe Kα emission lines in individual high-redshift AGN, providing insight into the conditions necessary to produce iron K-alpha emission and its evolution with redshift.**
- **We use our knowledge of current z=4-6.5 AGN in consideration of the scientific requirements of the Constellation-X mission.**

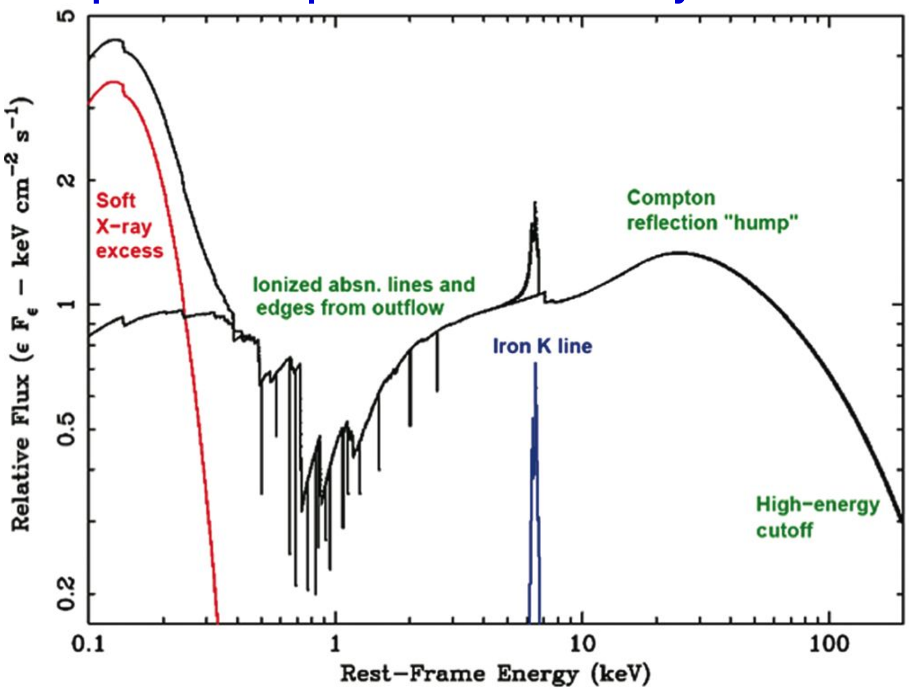
Vignali et al. (2005; astro-ph/0503301)



High-z AGN in the SRD: 1. Band pass

- **The energy band pass for high-z AGN shall be 0.25-40 keV. (always start with an executive statement for each performance parameter)**
- **Response from 0.7--7.0 keV will be required to cover all Fe Kα ionization states from 0 < z < 8**
- **Response from 0.25-10 keV at high spectral resolution will constrain the continuum: effect of absorption or continuum variation on the Fe Kα line may be determined.**
- **Measurement of the high-energy Compton cut-off (rest frame 50-200 keV, observed frame 10-40 keV) will constrain the state & structure of the X-ray emitting accretion-disk coronae** (e.g., Sobolewska, Siemiginowska & Zycki 2004)

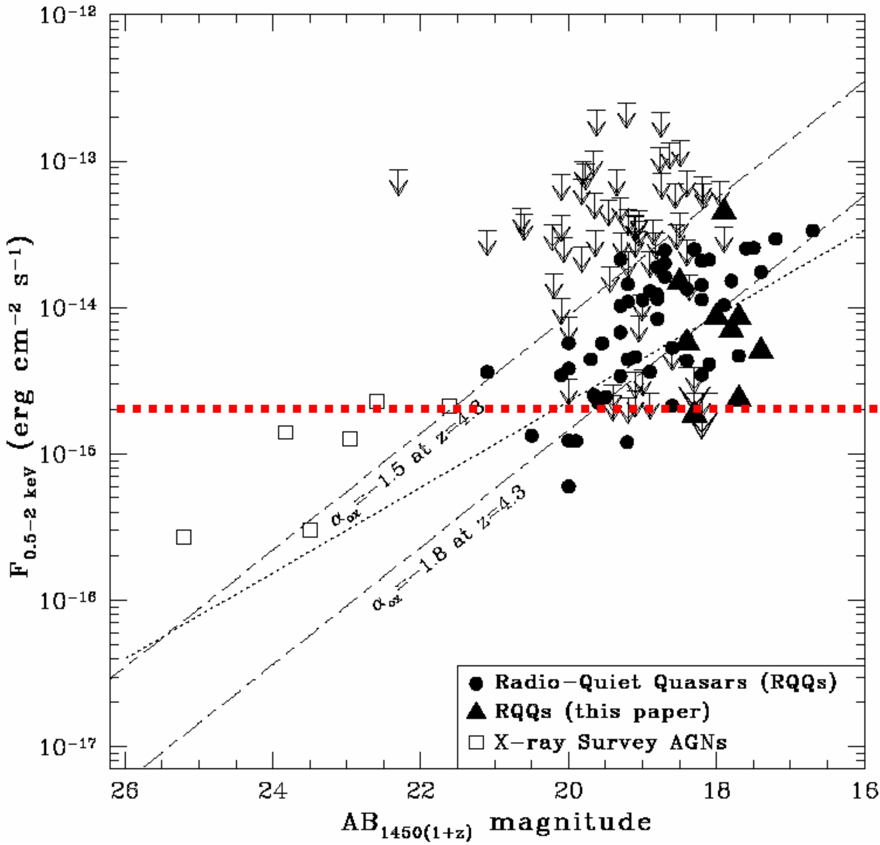
Spectral Components of AGN X-ray Emission



High-z AGN in the SRD: 2. Sensitivity/Effective Area

- To ensure broad constraint of high-redshift AGN (Type I QSOs), we should be able to study >~100 AGN
- There are currently ~ 100 z>4 AGN with fluxes > 2×10^{-15} erg cm^{-2} s^{-1} (0.5-2 keV, Γ=1.8) discovered by Chandra and XMM-Newton (e.g., Brandt et al 2004,astro-ph/0411355, Shemmer et al. 2006).
- In the 10-40 keV band, broad-band spectra of sources with fluxes of 10^{-14} (TBR, 10-40 keV) must be obtained to constrain the hard continuum emission.

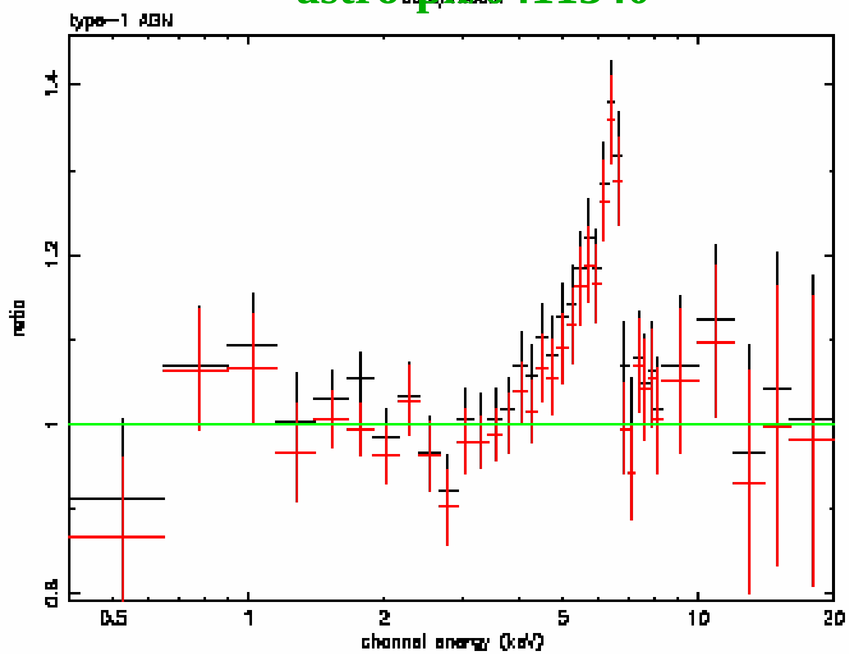
Vignali et al. (2005; astro-ph/0503301)



High-z AGN in the SRD: 3. Spectral resolution

- extremely high spectral resolution is not critical to learning much about z>4 luminous AGN
- Modest spectral resolution (1000 km/s) over the Fe Kα line (R~300 at observed energies of 0.7-1.3 keV) will be required.
  - Strebylanska et al. 2005 find possible Fe K lines with equivalent widths of hundreds of eV, corresponding to approximately 10^5 km/s width in the XMM Lockman Hole survey.
- Con-X should be able to measure such lines over 0 < z < 6.5, and as a goal should measure such lines from 6.5 < z < 8.0:
  - Note that there are X-ray detected SDSS sources up to z=6.5
  - There are no confirmed z>6.5 X-ray detected AGN due to the limitation of optical identification. Con-X may *identify* z>6.5 AGN via X-ray spectroscopy alone, with the Fe Kα line being a key identifier.
  - The Fe Kα line for AGN in the redshift interval 4 < z < 6.5 will have observed energies 0.85--1.3 keV, from 6.5 < z < 8 it is 0.71-0.85 keV.

Streblyanska et al (2004) astro-ph/0411340



Stacked XMM spectrum of 53 Type 1 AGN

High-z AGN in the SRD: 4. Angular Resolution

- Angular resolution is not a large driver for this science as the sources will be isolated, unresolved point sources. 15” angular resolution (HPD) will enable this science.
- Source confusion could result if the PSF was extremely poor due to the X-ray variability of the sky over multiple year timescales and the lack of guarantee of any concurrent higher angular resolution mission.
- This minimum angular resolution is 15", corresponding to 50-beam confusion limit the average distance between sources of X-ray flux 2×10^{-15} (0.5-2 keV) based on CDF number counts.
- An angular resolution of 5" would enable high galactic latitude blank-field observations with Constellation-X to obtain confusion-free spectroscopic measurements to $\sim 1 \times 10^{-16}$ erg cm^{-2} s^{-1} (0.5 - 2 keV, TBR).

High-z AGN in the SRD: FOV & "Other"

- 3.1.1.5 Instantaneous FOV
  - Field of view is not a strong driver for this topic, assuming targeted observations.
- 3.1.1.6 Other
  - There are no other considerations for this topic.

BEYOND EINSTEIN: From the Big Bang to Black Holes

Constellation X

The Constellation X-Ray Mission

Example Section of the SRD: Cluster fgas constraints on Dark Energy

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NASA

3 techniques for constraining cosmological parameters with Con-X cluster studies:

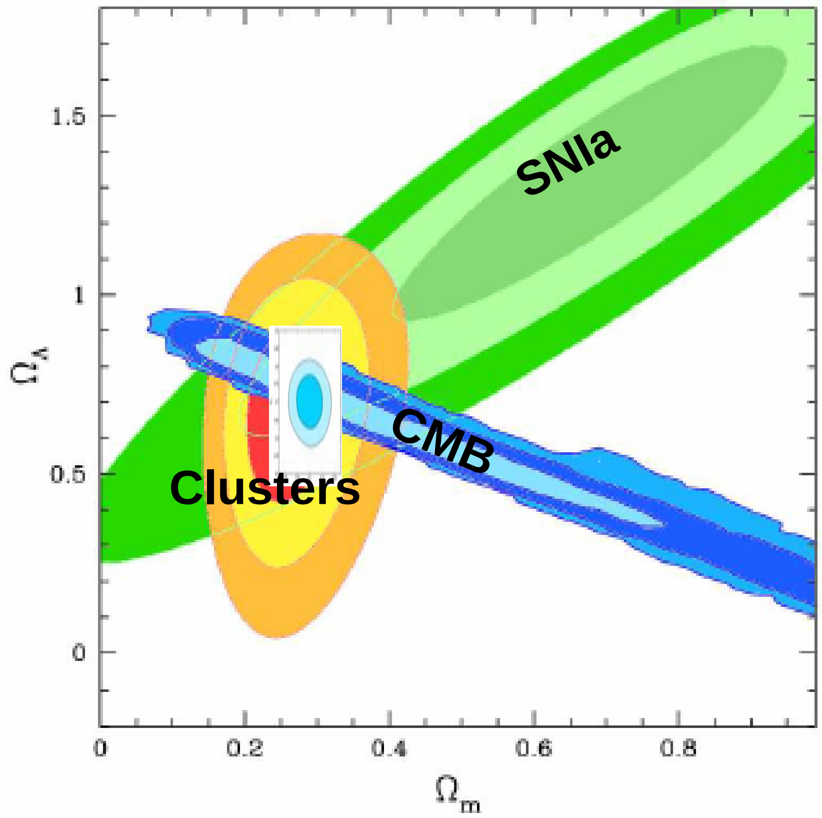
1. In combination with microwave background measurements the Sunyaev-Zeldovich technique to measure absolute distances
   - (BASELINE CON-X SCIENCE)

2. Measuring the evolution of the cluster parameters and mass function with redshift
   - (BASELINE CON-X SCIENCE)

3. Using the gas mass fraction in clusters as a “standard candle”
   - (GOAL CON-X SCIENCE)

Cosmological Parameters with Constellation-X

(Allen et al. 2005)



See also Rapetti & Vikhlinin Posters

- Constellation-X effective area critical to study large sample of clusters
- A large snapshot survey followed by deeper spectroscopic observations of relaxed clusters will achieve f_{gas} measurements to better than 5% for individual clusters:
  - Corresponds to Ω_M=0.300±0.007, Ω_Λ=0.700±0.047
  - For flat evolving DE model,

    w_0 = -1.00±0.15, w' = 0.00±0.27

Constraints are similar & complementary to SN Ia studies

SRD Investigation: Dark Energy EOS via fgas

- Simple, relaxed clusters of galaxies can be used as "standard candles" for relative distances using the observationally-verified prediction that the fraction of the cluster mass, in rich clusters, that is in baryons is independent of redshift.
- X-ray observations are crucial since ~90% of all the baryons are in the hot X-ray emitting gas.
- With its large collecting area, Con-X will be able to observe large samples (> 500 objects) over a wide redshift range (to z ~ 1) with high precision, which will be required to use this distance determination method.
- Simulations show that Constellation-X data alone can obtain uncertainties on w to ±0.05.
- To utilize this technique, Constellation-X must reach scales in the cluster where gravity is dominant and have sufficient spatial resolution to recognize merging clusters and separate out the complex physics in the centers of clusters.

Dark Energy via fgas in the SRD : 1. Bandpass

- The most important bandpass for studying Dark Energy via the X-ray gas mass fraction in clusters is 0.5-10 keV, with 0.5-7 keV being most important. Due to redshift effects, collecting area at E>10 keV is not as important. The bandpass is largely driven by the typical X-ray temperatures of large, relaxed clusters of galaxies (kT~2 keV – 10 keV) and the median redshift of the anticipated sample (z=1)

Dark Energy via fgas in the SRD
2. Sensitivity/Effective Area

- Collecting area and sensitivity are major drivers for this science topic.
- Routine, short observations (~5ks) of clusters of galaxies with 0.5-10 keV flux of 10^{-13} erg cm^{-2} s^{-1} (TBR) must yield high signal/noise spatially resolved images which are needed to determine if clusters are relaxed.
- Moderate-length observations (~20-40 ks) should measure the ICM emission at surface brightness values of ~3×10^{-16} ergs $cm^{-2}s^{-1}$ $arcmin^{-2}$ over 1-3 keV, TBR).
- The relevant target sample is the 1000 most luminous, relaxed clusters in the Universe.
  – These clusters will have "bolometric" X-ray luminosity >10^{45} erg s-1 (0.5-10 keV, TBR). This sample may have a median redshift of z=1(TBR) , and the science is enabled if these 1000 clusters can be observed in <5 ks (TBR) so that the total observation time is reasonable
- Sensitivity:
  – <~5 ks to determine if they are relaxed or not. We should be able to collect ~1000 counts (TBR) for a 10^-13 (0.5-10 keV) source in 5 ks. Assuming kT=5 keV, 0.3 solar abundances, and z=1 with a MEKAL model, a collecting area of TBD cm^2 (TBD) is required.

Dark Energy via fgas in the SRD

2. Sensitivity/Effective Area (Continued)

- Surface brightness sensitivity:
  - Chandra and XMM-Newton are unable to detect cluster X-ray emission to the virial radius because their particle backgrounds are too high.
  - Exposure time to detect cluster emission rises DRAMATICALLY once cluster surface brightness falls below the particle background.
  - Both Chandra and XMM-Newton have specific particle backgrounds of approximately 10^{-2} counts s^{-1} keV^{-1} cm^{-2} at 1 keV.
  - Baseline Con-X one needs to reach 4 x 10^{-3} counts s^{-1} keV^{-1} cm^{-2} at 1 keV (corresponding the ~3x10^{-16} ergs $cm^{-2}s^{-1}$ $arcmin^{-2}$ over 1-3 keV) to do surface photometry to the virial radius for luminous clusters at moderate redshifts (z~0.3)
  - Note that one does not absolutely need to reach a virial radius (r500, 0.6 virial radii) may be fine (S. Allen)
  - **FULL SCIENCE SIMULATIONS, INCLUDING BACKGROUND, ARE NEEDED TO CONSTRAIN THE BACKGROUND REQUIREMENTS.**

Dark Energy via fgas in the SRD: 3. Spectral Resolution

- Spectral resolution is not a strong driver.
- "CCD-quality" (~50 eV) spectral resolution is sufficient to adequately measure temperatures and and abundances in clusters for fgas measurements in dynamically relaxed clusters.
- Spatially-resolved spectroscopy is key.
- Higher spectral resolution
  - will be needed to remove soft background in cluster centers
  - highly advantageous for clusters that may not be completely dynamically relaxed as accuracy of mass measurements is reduced as the assumption of hydrostatic equilibrium breaks down.
  - Spectral resolution of at least $\Delta E = 4$ eV FWHM will be essential to:
    - remove the soft background in the central 1’ x 1’ (TBR, S. Allen) region
    - probe the turbulent velocities in dynamically active clusters (whole FOV)
    - gauge the effects of inhomogeneities & shocks on the emission-weighted X-ray parameters (whole FOV)

Dark Energy via fgas in the SRD: 4. Angular Resolution

- This science will truly be enabled by obtaining the GOAL angular resolution of 5” (TBR)
- **SCIENCE SIMULATIONS ARE NEEDED TO QUANTIFY THE EXACT VALUE OF THE MINIMUM ANGULAR RESOLUTION REQUIRED**
- Having low scatter on measured cosmological parameters (such as Ω_M) requires RELAXED clusters (in hydrostatic equilibrium)
  - regular X-ray morphologies
  - low ellipticities
  - minimal centroid variation
  - sharp central brightness peaks centered on their dominant elliptical galaxies
- One must also remove bright point sources.
  - Brightest point sources: central luminous AGN with LX ~ 10^44 erg/s (TBR), ~3.5×10^{-13} ergs $cm^{-2}s^{-1}$ (0.5-10 keV, TBR)
  - AGN throughout the cluster: X-ray luminosities of ~10^43 erg/s (TBR) should be removed, corresponding to point sources with X-ray flux ~3.5×10^{-14} ergs $cm^{-2}s^{-1}$ (0.5-10 keV).

Dark Energy via fgas in the SRD:
4. Angular Resolution (Continued)

- One needs angular resolution corresponding to spatial scales of <=50 kpc (TBR) to identify relaxed clusters and remove point sources from z=0.15 to z=2.0.

Spatial Scale of PSF(HPD)

BLUE numbers satisfy 50 kpc resolution requirement, but the true number will be established only by simulations

z	kpc/''	5''	10'' (kpc)	15''
z=0.15	2.614 kpc/"	**13**	**26**	**39**
z=0.3	4.454 kpc/".	**22**	**44**	66
z=0.5	6.104 kpc/"	**30**	61	91
z=0.7	7.145 kpc/"	**35**	71	106
z=1.0	8.008 kpc/"	**40**	80	120

- DE effects are prevalent at z>0.3 (TBR).
- NOTE: The baseline Constellation-X mission (15" HPD) will NOT reach z=0.3

Dark Energy via fgas in the SRD:

5. Instantaneous FOV

- Dark energy measurements require that the surface brightness profile of clusters be measured to r2500 (0.25 virial radii, TBR!)
- For a 10^45 erg/s relaxed cluster the virial radius is typically 2 Mpc (TBD) so r2500 is ~0.5 Mpc. The largest clusters for fgas studies will be at lower redshifts (z~0.3), so the FOV radius should be a 2' (TBR), or of angular size 4' x 4' (TBR)
- Note: S. Allen says r500 is a better target and that a large FOV is highly desirable

6. Other

- Diffuse source sensitivity as a function of detector background and telescope focal length is described in detail in a memo from Mark Bautz